Thresholds for Control of Potential Hazards in Occupational Environments

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The goal of an environmental hygiene-occupational medical program should be to assist individuals in the maintenance of their health. The following will concentrate on some aspects of evaluation and control of potential hazards in work environments. Before starting on the occupational factors of importance to health, one fact should be emphasized.

A review of the record of visits to the medical departments in industrial plants shows that only approximately 20% of the visits are for treatment of illness or injury directly related to potential hazards of the work environment. Headaches and upset stomachs that result from poor interpersonal relations with a fellow worker or foreman should not be considered illnesses related to potential hazards inherent in the work environment. There may be many more visits for such illnesses than from exposure to a chemical or physical agent. Such illness does need to be treated and the causes recognized and minimized both for maintenance of health and for efficient operations.

Another source of data on occupational versus non-occupational illness and injury is the record of non-occupational group sickness and disability and Workmen's (or should it be Workperson's) Compensation insurance costs. A number of industrial operations employ a sufficient number of people to obtain a rating different than the general population for non-occupational group sickness and disability insurance. The medical costs for a broken leg in a skiing accident should be about the same as a comparable broken leg from an industrial accident. There will be Workperson's Compensation payments while unable to work and there may be payment for residual disability in the case of the broken leg from an industrial accident. A review of the costs of non-occupational sickness and disability insurance and Workperson's Compensation insurance, both experience rated, has shown that the Workperson's Compensation cost is 15–20% of the total and non-occupational group is 80 to 85%. Another review has shown 876 days lost for on-job accidents and 6,022 days lost for off-job accidents (Baldwin, 1973).

We concentrate on the minor portion of the total health maintenance problem when we concentrate on occupational causes of sickness and disability. It should be much easier to measure and control potential hazards from a few chemical and physical hazards on a specific job than it is to measure and control the myriad potential hazards to which an individual is exposed off the job. Before we can control the potential hazards, we should know what they are and how to measure them.

Paracelsus wrote 450 years ago "dosis sola facet venenum," dose alone makes a poison. In terms of environmental hygiene, the *rate* of dosing alone changes a potential hazard to a hazard. Therefore, we must know what *rate* of dosing can be handled by the human body without injury. The emphasis is on *rate* because we are dealing with the dynamic system of intake-detoxication-excretion.

The Threshold Limit Values of the American Conference of Governmental Industrial Hygienists and the allowable limits of exposure established by the Occupational Safety and Health Administration for chemical substances are

expressed as concentrations, not as rates, for less than a work day. The rate of systemic dosing can be calculated from the concentration in air if the breathing rate and rates of absorption through the lungs are known. There is some information on some chemicals relative to rates of absorption through the lungs but certainly not enough to specify the range of rates of absorption over the range of temperatures, work loads, concentrations of the chemical and individual variations encountered in industry. Approximately 20 percent of the mercury vapor in a single inhalation is present in the exhaled air of a person who has not imbibed. But after a couple of beers, approximately 50% of the inhaled vapor appears in the exhaled air. How many other intakes of foods, beverages or drugs can cause similar alterations in absorption of inhaled chemicals?

We have some measure of the limits of rates of caloric utilization and hence of oxygen utilization and breathing rates. Minimum recommended daily caloric requirements of a sedentary male are approximately 2500 calories per day. The maximum caloric expenditure from continuous hard work is approximately 6000 calories per day. If 1500 of the calories in both cases are expended in the 16 hours off work, then the variation in calories expended in work may range from 1000 to 4500 for the 8-hour work day. Does the person breathing at a rate to expend 4500 calories have 4.5 times the exposure of a person breathing at a rate to expend only 1000 calories in an 8-hour work day? Or does the rate of absorption change as the breathing rate changes?

The fact that 20% of inhaled mercury vapor is present in exhaled air has been mentioned. If a person takes one breath of air containing 0.5 mg/m^3 of mercury vapor, the exhaled air should contain 0.1 mg/m^3 of mercury vapor. If this is followed by an inhalation of air containing 0.1 mg/m^3 of mercury, is any of this mercury absorbed, does it constitute a systemic dose? If a person alternately breathes 0.5 mg/m^3 and 0.1 mg/m^3 of mercury vapor in uniform breath volume at uniform rate for an 8-hour work day, is the effective exposure 2 mg hours/m^3 or is it 2.4 mg hours/m^3? Assuming we determine the effective exposure, i.e. what fraction of the exposure is absorbed, this may not be the effective systemic dose. Once absorbed, a chemical may undergo changes and the rate of change may be the limiting factor in controlling the potential hazard. The chemical that is dosed and its metabolites may have different effects on different organs.

The brain is considered the critical organ for mercury vapor and the kidney the target organ for ionic salts of mercury. Animals given a dose of elemental mercury accumulated approximately 10 times as much mercury in the brain as animals given an equal dose of an inorganic salt of mercury. This is true for both intravenous and inhalation dosing—at the rates of dosing used in the experiments (Magos, 1967; Rabinovitz, 1972; Viola and Cassano, 1968).

The rate of oxidation of elemental mercury in blood has been studied (Clarkson, et al., 1961). It is logical to assume that there is a rate of oxidation such that elemental mercury absorbed through the lungs is oxidized to ionic mercury before it gets to the brain. Elemental mercury vapor dosed at this rate would have the potential hazard of an inorganic salt of mercury for the brain.

If some of the mercury absorbed from inhalation of one breath of air containing 0.5 mg/m^3 of elemental mercury vapor travels from the lungs to the brain without oxidation but none of the mercury absorbed from inhalation of one breath of air containing 0.1 mg/m^3 of elemental mercury vapor travels from the lungs to the brain without oxidation, the two exposures can have a tenfold difference in potential hazard for damage to the critical organ, the brain. Is there a 10-fold difference in brain loading from 10 minutes exposure to 0.6 mg/m^3 of elemental mercury vapor plus 50 minutes of no exposure compared with 60 minutes exposure to 0.1 mg/m^3 of elemental mercury vapor? There are some data to

TABLE I.—Summary Tissue Analyses (from Smith, 1967).

	Hg Concentration, μg/g (Dry Weight)			
	Control	0.1 mg/m³	0.5 mg/m³	1.0 mg/m³
Kidney	23	130	428	930
Brain				
Medulla	0.1	0.2	24	55
Cerebellum	0.4	0.6	11	64
Occipital	0.2	0.4	15	84
Frontal	0.3	0.6	12	87

indicate that the brain loading of mercury is not proportional to dose but that the kidney loading is proportional in monkeys (Smith, 1971).

Kidney function tests showed no impairment of kidney function in any of the test groups. The monkeys exposed to 1.0 mg/m³ did exhibit signs of neurological effects—shyness, irritability—in the first months of the exposure but appeared to adapt with time.

Once absorbed and distributed, mercury leaves the body via urine, feces, sweat, hair, nails and expired air. Values for urinary, fecal and biliary mercury of monkeys exposed to 0.1, 0.5 and 1.0 mg/m³ of elemental mercury vapor are shown in Table II.

The extremely high fecal mercury values for the 1.0 mg/m³ exposure group may be the result of ingestion of mercury during grooming; mercury condensed on fur at this dose.

Urinary mercury is used as a guide in evaluating and controlling exposure to mercury in work environments. On a group average basis, urinary mercury has been found to correlate with estimated time-weighted average workday exposure. Fig. 1 illustrates the relation. From this plot it can be determined that 0.15 mg/l of mercury in urine corresponds to an estimated time-weighted average workday exposure of 0.05 mg/m³. On the basis of this, some persons have suggested that there should be a limit of 0.15 mg/l for urinary mercury. It can be seen from Table III that a limit of 0.15 mg/l for urinary mercury would fail to detect over 60% of persons exposed to more than an estimated time-weighted average 0.05 mg/m³ of mercury vapor for the workday. It would also erroneously detect as excessively exposed a significant fraction of persons not actually overexposed.

TABLE II.—Urinary, Fecal, and Biliary Mercury Concentrations (from Smith, 1967).

Group	Urine mg/l	Feces mg/kg	Bile mg/l
Control	0.03	0.36	0.12
0.1 mg/m³	0.06	0.58	0.72
0.5 mg/m³	0.17	1.56	3.73
1.0 mg/m³	1.45	54.8	14.50

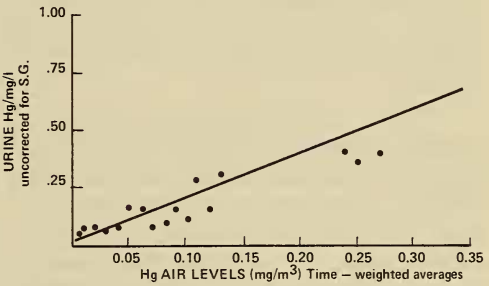

Fig. 1.—Concentrations of mercury in urine (uncorrected for specific gravity) in relation to time-weighted average exposure levels (from Smith, et al., 1970).

Another possible error in assessing potential hazard on the basis of urinary mercury is the possibility of equal urinary mercury concentration from equal doses

TABLE III.—Relationship of Mercury Exposure to Mercury Levels in Urine Uncorrected for Specific Gravity (expressed as percentage of each exposure level group within designated ranges of urine mercury levels) (from Smith *et al.*, 1970).

TWA Exposure Level Groups (mg/m^3)	Number of Workers	Percentage of Group Within Urine Level Range (mg/liter)					
		<0.01	.01–.10	.11–.30	.31–.60	.61–1.0	>1.00
Controls 0.00	142	35.2	62.7	2.1	0	0	0
<0.01	29	6.9	86.2	6.9	0	0	0
0.01–0.05	188	6.9	66.0	24.5	2.7	0	0
0.06–0.10	91	0	62.6	30.8	6.6	0	0
0.11–0.14	60	3.3	18.3	31.7	16.7	23.3	6.7
0.24–0.27	27	0	14.8	29.6	44.5	7.4	3.7

of ionic and elemental mercury that are not equal in potential hazard. There also is the possibility that the numerically equivalent exposures of 0.6 mg/m^3 for 10 minutes and 0.1 mg/m^3 for 1 hour will yield essentially the same urinary mercury values but, as indicated previously, may have different potential for damage.

The preceding has outlined some of the possible biological factors that can lead to erroneous assessment of potential hazards. Another factor that can cause error is the actual measurement of exposure. The micro-environment around a worker may have a different concentration of mercury vapor than the general work environment. This is shown in Table IV. Most published work on effects of exposure to mercury have based estimates of exposure on measurements in the general work environment. This can grossly underestimate actual exposure. Also, it is possible to have exposure continue beyond the workday from mercury on the body and clothing.

Hippocrates observed that excessive exposure to mercury appeared to be related to certain disorders of certain workers. Approximately 2400 years later we have a rough estimate of what the limit of exposure can be without damage. There is disagreement regarding the need for a greater margin of safety than that provided by 0.1 mg/m^3. Is the benefit to be derived from the increased margin of safety of a limit of 0.05 mg/m^3 worth the cost of decreasing the limit?

The effects of mercury, regardless of form, are systemic. Another example of a Threshold that does not appear to be based on mode of toxic action of the compound is the Threshold for phosgene. The effects of exposure to phosgene appear to be solely on the surface layers of the lungs without direct effect on other organs. There are effects from loss of fluid into the alveolar spaces of the lungs but the fluid and electrolyte imbalance is not sufficient to cause death. The present allowable limit for exposure to phosgene is 0.1 ppm. Several years ago the Threshold Limit Value Committee of the American Conference of Governmental Industrial Hygienists recommended that there should be a ceiling but that recommendation was withdrawn. The Occupational Safety and Health Administration limit is also 0.1 ppm. The American Conference of Governmental Industrial Hygienists recommends limiting excursions to 3× the Threshold Limit Value for periods not to exceed 15 minutes. The OSHA limit does not specify what range of excursion may be permitted for phosgene other than that the 8-hour average shall not exceed 0.1 ppm. The total exposure would be 48 ppm minutes/m^3 for 8 hours at 0.1 ppm.

TABLE IV.—Mercury Vapor Concentrations in Air Near Contaminated Clothing and Skin.

October 24–26, 1972

Locker Room	Mg Mercury/ Cubic Meter of Air
General Room Atmosphere	0.03–0.04
Air Near	
1. Outer clothing furnished by company and laundered daily; worn one shift before measurements	0.1 –0.2
2. Gloves	0.08–0.2
3. Hands (before washing)	0.5 –0.6
4. Clean Hands (washed)	0.04–0.08
5. Sweater (employee in mercury recovery area)	0.2 –0.5
6. Rubber Coated Shoes (inside)	0.02–0.05
(outside)	0.10–0.5
7. Cotton undershirt worn approximately 6 hours in cell room. Person had no known contact of outer clothing with liquid mercury nor salts of mercury	0.01
8. Cell Room, breathing height—October	0.06–0.116
—November	0.02–0.08

A person is unlikely to breathe 48 ppm of phosgene for 1 minute, an equivalent exposure. This concentration is immediately severely irritating to the respiratory tract. A person might breathe 5 ppm for 1 minute and repeat this each hour for 8 hours; a total exposure of 40 ppm minutes/m^3. Such an exposure might cause damage. Certainly under the standard operating procedures used by phosgene manufacturers, the person who breathed 5 ppm for 1 minute would be unlikely to repeat it the next hour; he or she would be in the medical department under observation.

There are sampling and analytical methods that can detect 0.1 ppm of phosgene in a small volume of air. Air is drawn through a chemically impregnated filter paper. The colored reaction product on the filter paper can be extracted in chloroform and quantitated colorimetrically. By changing filter papers every few minutes, it would be possible to determine short-term peak exposures. The infrequent peak exposures may be more important than the uniform low level exposure relative to long-term effects of exposure to phosgene. Phosgene producers are planning a long-term study to try to improve our knowledge of the effects of exposure to phosgene.

The problem of evaluating long-term effects of low level exposure to tolylene diisocyanate are similar to those for phosgene with one exception. The allowable limit for tolylene diisocyanate is 0.02 ppm and we do not have sampling and analytical procedures to tell us whether an exposure is 0.2 ppm for 1 minute or 0.02 ppm for 10 minutes. In terms of potential hazard, these two exposures are probably different.

Congress provided enough "weasel words" in Section 6(b)(5) of the Occupational Safety and Health Act to make it possible for the Secretary of Labor to comply with the Act in setting standards. The Secretary "shall set the

standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life."

No matter how much data we collect and how thoroughly we apply statistical methods to the evaluation of the data, the only really meaningful datum to the individual employee is which part of the LD_{50} or effective $dose_{50}$ or other measure she or he is in. The ultimate decision of whether a potential hazard is being adequately controlled is determined by careful periodic medical evaluation of each individual. The Occupational Safety and Health Act provides for the granting of a variance when the preponderance of evidence shows that the "conditions, practices, means, methods, operations, or processes used or proposed to be used by an employer will provide employment and places of employment to his employees which are as safe and healthful as those which would prevail if he complied with the standard." If a plant has been operating unchanged for 100 years, the average length of employment has been 45 years and all retired employees have died when over 90 years of age as the result of automobile accidents that occurred on the way home from their daily 2 hours of tennis, that would probably be acceptable as a preponderance of evidence that the work environment of the plant was as healthful as it would be if an OSHA standard was met.

References Cited

Baldwin, Doris. 1973. Safety and Health: Grounds for Competition. A Coffee Company's Multi-Plant Contest Combines Some Unusual Ingredients to Lower Worker Injury Rate. Job Safety and Health, 1: 18 (December 1973) United States Department of Labor, Occupational Safety and Health Administration.

Clarkson, T. W., Gatzy, J., and Dalton, C. 1961. Studies on Equilibrium of Mercury Vapor in Blood. Division of Radiation Chemistry and Toxicology, University of Rochester Atom. Ener. Project, Rochester, N.Y. U.R. 582.

Magos, L. 1967. Mercury-blood interaction and mercury uptake by the brain after vapor exposure. Environ. Res. 1: 323.

Rabinovitz, S. H. 1972. The uptake of mercury in the brain of gerbils chronically exposed to mercury vapor and to mercuric nitrate. Thesis for Doctor of Philosophy, Wayne State University.

Smith, R. G. 1971. The Effects of Chronic Exposure to Mercury Vapor. Presented at the 1971 American Industrial Hygiene Association Conference, Toronto, Canada, May.

Smith, R. G., Vorwald, A. J., Patil, L. S., and Mooney, T. F., Jr. 1970. Effects of exposure to mercury in the manufacture of chlorine. Amer. Ind. Hyg. Assn. J. 31, Nov.-Dec.

Viola, P., and Cassano, G. B. 1968. Effect of chlorine on mercury vapor intoxication. Autoradiographic study. Med. Lav. 59(6–7): 437–44.